# Arctic Tortoise Technical Paper

REVISION 1


The following Arctic Tortoise technical information is presented in the same format as the Required Contents in the Technical Paper Requirements.

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1.a.1 – Ground contact is via 4 rubber tires consistent with the stock configuration of a commercial 1992 Jeep Cherokee.

1.a.2 – Locomotion is accomplished via stock configuration Jeep Cherokee drive train. Steering is via stock Jeep Cherokee power steering components. Braking is via stock Jeep Cherokee anti-lock braking system.

1.a.3 – Braking, Transmission shifter and Transfer case shifter are operated via individual electric linear actuators. Steering is via electric stepper motor through reduction. Throttle control is via a commercial cruise control vacuum actuator.

1.b.1 – Vehicle power is a 4.0L, 171 HP internal combustion 6-cylinder engine. Electrical generation and distribution will be via a 24-volt, 85 A alternator and sealed batteries.

1.b.2 – 225 ft lbs @ 4000 RPM, 171.36 HP, 127.8 KW

1.b.3 – Fuel capacity will be 44 Gal US, unleaded gasoline in safety fuel cells.

1.c.1 – The reaction control system will be a distributed computing system. I/O control is at the heart of this system rather than computing power. By distributing the multitude of sensors over several motherboards we can combine like information in different sets.

The team has access to a dozen identical PC/AT class boards with processors and memory donated by Phillip Rulon of Persean Development. Three to six boards are to be networked together to form the reaction control system. These boards will run NetBSD UNIX as a base operating system. I/O hardware will be parallel and serial ports, I/O cards and various A to D converters as needed. Hardware communications will be done with numerous C and C++ algorithms built as needed. These will be accessed using object oriented scheme interpreter scripts to provide a fourth level programming hierarchy to expedite vehicle programming. Several scheme scripts will be distributed to handle the multitude of sensor information, checking the health of each sensor and determining a result from each set of interrelated sensors. This information is passed to the next level of scheme scripts that interpret the sensor information based on consistent information from all sensors and their confidence levels. These scripts pass the conclusions to the next level of code that will result in sending obstruction information back to the terrain map or make immediate reaction to the one and only vehicle program that actually drives the vehicle.

1.c.2. – Refer to attachment H

1.d.1 - The image and map data utilized will be from a number of different sources. Satellite data will be Ortho-rectified Landsat, ETM and ASTER. Various vector coverages will be utilized as overlays and cover definitions for terrain types and known possible transit corridors or obstacles. Examples of vector data source are Digital Chart of the World, National Geographic Digital Topographic Maps, and GSHHS – Global Self-consistent, Hierarchical High-resolution Shoreline Database.

1.e.1 – A 2-D active scanning laser ranger with an 80-meter sensing horizon and a 100-degree field of view will be used for object detection and relative positioning. These measurement data correspond to the surrounding contour scanned by the device.
An active 24.725 GHz Doppler radar system (Eaton VORAD EVT-300) with a sensing horizon of 100 meters and 12 degree field of view will also be utilized for obstacle detection/avoidance as well as enhanced road following capability. The radar system will include a forward-looking antenna as well as range-gated side sensors.
Active 50KHz ultrasonic sonar with a sensing horizon of 10 meters will be used for near obstacle detection to the front, rear and sides of the vehicle.

1.e.2 – All of the sensors will be mounted in a fixed position and will be controlled by the environmental processor. The laser scanner will be mounted in the windshield area of the vehicle looking forward over the hood. The forward-looking radar sensor will be mounted just above the front bumper. The side radar sensors will be mounted in the approximate center of the 2 sides of the vehicle oriented 90 degrees each side of forward.
The front sonar sensor will be mounted just above the front bumper. The side sonar sensors will be mounted in the approximate center of the 2 sides of the vehicle oriented 90 degrees each side of forward.
Two sonar sensors will be mounted just above the rear bumper, equally spaced from the center and oriented 180 degrees from forward.
Refer to attachment A

1.f.1 – Vehicle sensors are – encoders on all 4 wheels, 3-axis accelerometer, steering position, brake position, throttle position, RPM, low oil pressure, transmission shifter position, transfer case shifter position, air conditioning information which is used for temperature management in the water tight electronics enclosure and front and rear tactile sensors (so we can “sorry”).

1.f.2 – Braking/deceleration commands are issued as rate-of-deceleration. The vehicle program will attempt to execute the issued deceleration using the throttle and/or brake actuators while monitoring the accelerometer for compliance. Throttle control commands are issued as desired speed. The vehicle program will attempt to execute the desired speed using the vacuum throttle actuator while monitoring wheel encoders and engine RPM for compliance. The throttle actuator is in series with n/c brake position contacts so that any application of the brakes forces the throttle to idle under spring control. Steering commands are issued as position and rate-of-turn. The vehicle program will attempt to execute the issued steering commands within the constraints of an algorithm that limits the rate-of-turn for the vehicle speed. Stepper counts and steering position are monitored for compliance.
If conflicting control commands are issued they are prioritized as to their level of urgency.

1.g.1, 1.g.2 – The NAV system consists of two components.  The first component is a Trimble "AgGPS 114" DGPS receiver.  This is an L-band system, which uses Omnistar differential corrections.  The unit has sub-meter accuracy when the Omnistar signal is available.  The second component is an integrating compass system.  The NAV system provides three pieces of information to the vehicle: Latitude, Longitude, and an error factor (in Meters).  This error factor is primarily used during GPS outages to allow the vehicle to stay within the route boundaries.

The nature of GPS systems is such that accuracy improves with time, when integration techniques can be used.

The Compass is a KVH “Azimuth 1000” fluxgate compass.  Wheel encoders on the vehicle are used to compute distance traveled.  The integrating compass uses the heading info from the KVH compass, and “integrates” this over the distance read by the encoders.  This system is accurate during short distances, but becomes progressively less accurate with time.

The Arctic Tortoise NAV system will combine the info from the GPS and the integrating compass by using a Kalman filter.  This filter will provide better system accuracy than is possible either the GPS or the integrating compass alone.  In addition, the NAV system will provide guidance information during periods when GPS does not work or cannot receive the signal.

1.g.3 – The NAV system provides vehicle location.  The route boundaries are provided by DARPA.  An internal map grid is used with the vehicle in the center of that grid. This map grid is essentially a two dimensional array inside the GIS computer.  Route boundaries are plotted onto the grid, during real time.  In order to account for possible NAV errors, boundaries must be further defined. Each route boundary consists of two components: A “soft” boundary and a “hard” boundary.  A soft boundary is the inside most boundary within the max NAV error. A hard boundary is the outermost boundary, as defined by NAV error. For example:  Suppose route boundaries are 20 meters apart, and the vehicle is in the center (refer to attachment B).  Suppose that the vehicle position is known to within two meters.  The soft boundaries are two meters inside the DARPA boundary and the hard boundaries are two meters outside the DARPA boundary.  Staying within the soft boundaries guarantees that we are on course.  Conversely, going outside the hard boundaries guarantees that we are outside the course boundaries.  Every effort will be made to navigate the entire course inside the soft boundaries.  A soft boundary is treated the same as a “hard obstacle” and will be avoided by the vehicle.  In the event that soft boundaries overlap (i.e. narrow coarse boundaries combined with high errors), the vehicle will disregard soft boundaries and define hard boundaries as hard obstacles.  The vehicle will attempt first to navigate the center of the course, but will not exceed hard boundaries in any event.

1.h.1 – There will be no signals broadcast from the vehicle except for those used in environmental sensing.

1.h.2 – The only externally broadcast signals received by the vehicle will be for geo-positioning.

1.i.1 – The vehicle will not refuel during the race.

1.i.2 – There are no servicing activities planned for the checkpoint.

1.j - Vehicle positioning will be accomplished in one of two ways.

1 – Via tethered control box which, when plugged in will allow remote control of vehicle start and all actuators. The connector for the tether will be positioned so as to facilitate quick release without hindrance. Upon disconnect, the vehicle will be in E-Stop/Shutdown, see 3.d.1. A tether jumper plug will be used for autonomous operation.

2 – Disengage the steering and transfer case shifter actuators per 3.d.3. Manually shift the transfer case into neutral then operate the locking *brake release* switch. This will disable RLY1 (force a *disable E-Stop* if active), see 3.d.1 and force brake actuator to full release. Vehicle then can be manually positioned.

3.a – Top speed of vehicle has not been tested, but current design mandates that top speed be limited to 50 MPH.

3.b – Maximum range will depend on conditions but is calculated to be 300 – 350 miles.

3.c.1 – Two Fuel Safe Systems CT122B fuel cells will be mounted in the back of the Jeep to further reduce the possibility of damage. The stock fuel tank will be removed.

3.c.2 – There is no automatic fire suppression equipment on the vehicle.

3.c.3 –Audible alarm – Ademco AD702
Visual alarm – Federal Signal Firebolt amber strobe

3.c.4 – Sealed batteries, brake light, manual E-stop switches, emergency brake and fire extinguisher.

3.d.1 – Refer to attachment F
The *normal E-stop* binary signal will be monitored by the vehicle control processor. Upon activation, the vehicle processor will initiate an immediate braking routine and alert the main processor. Immediate braking routine will cause the throttle to go to idle and the brakes applied to the anti-lock position to bring the vehicle to a stop as quickly as possible. Until the vehicle comes to a complete stop, the main processor will continue to monitor sensors and issue appropriate steering commands. When the vehicle has stopped the main processor will pause route execution while monitoring all vehicle sensors until the *normal E-stop* signal is cleared.

The *disable E-stop* signal will be used to control a N/O relay (RLY2) whose contacts are in series with the two manual E-stop switches, N/C *brake release* contacts, a tether control jumper and the coil of a multi-pole relay (RLY1). Loss of any path will result in a disable E-stop. RLY1 (enable/disable) is closed when 12 volts is applied through RLY2, N/C *brake release* contacts, tether control jumper and the 6 Manual E-stop switches. PB1 (MOM N/O) is used activate the N/O relays for the vehicle systems/ignition and power buss (actuators and sensors). These relays are held activated through RLY1. When RLY1 drops (*disable E-stop*) power to the vehicle systems/ignition and power buss is removed and the brake actuator is forced to the full anti-lock position. Re-activation of the vehicle requires clearing the *disable E-stop* and manually operating PB1. Other contacts on RLY1 are used to switch control of the brake actuator between the vehicle processor and the default (maximum brakes). Unswitched power will be provided for Grand Challenge equipment and default brake activation.

3.d.2 – Six emergency stop pushbutton switches, Omron A22 series or equivalent are utilized. Three will be mounted on each side of the vehicle in an easily accessible position and clearly marked per the rules. The emergency stop switches are in series with the disable E-stop relay (RLY2) and will force the disable E-stop as described in 3.d.1.
The remote control tether has a jumper that is also in series with disable E-stop relay (RLY2). Disconnecting the remote control from its socket will force the disable E-stop as described in 3.d.1. A tether jumper plug will be used for autonomous operation.

3.d.3 – The transfer case shifter and brake actuators are connected via a removable pin. Removing the pin will allow the transfer case to shifted into neutral manually, thereby disengaging the drive train. The steering actuator clutch can be disengaged to allow manual steering. A conventional tow truck can tow the vehicle.

3.e.1 – SICK LMS-211 Laser Scanner, 905 nm IR, 1 mw, Class 1 (eye safe)
Refer to attachment G
Eaton VORAD EVT-300 24 GHz Radar
Refer to attachment I
POLAROID 6500 Ultrasonic Ranger, 50 KHz

3.e.2 – Audible Alarm 118 db @ 10 feet

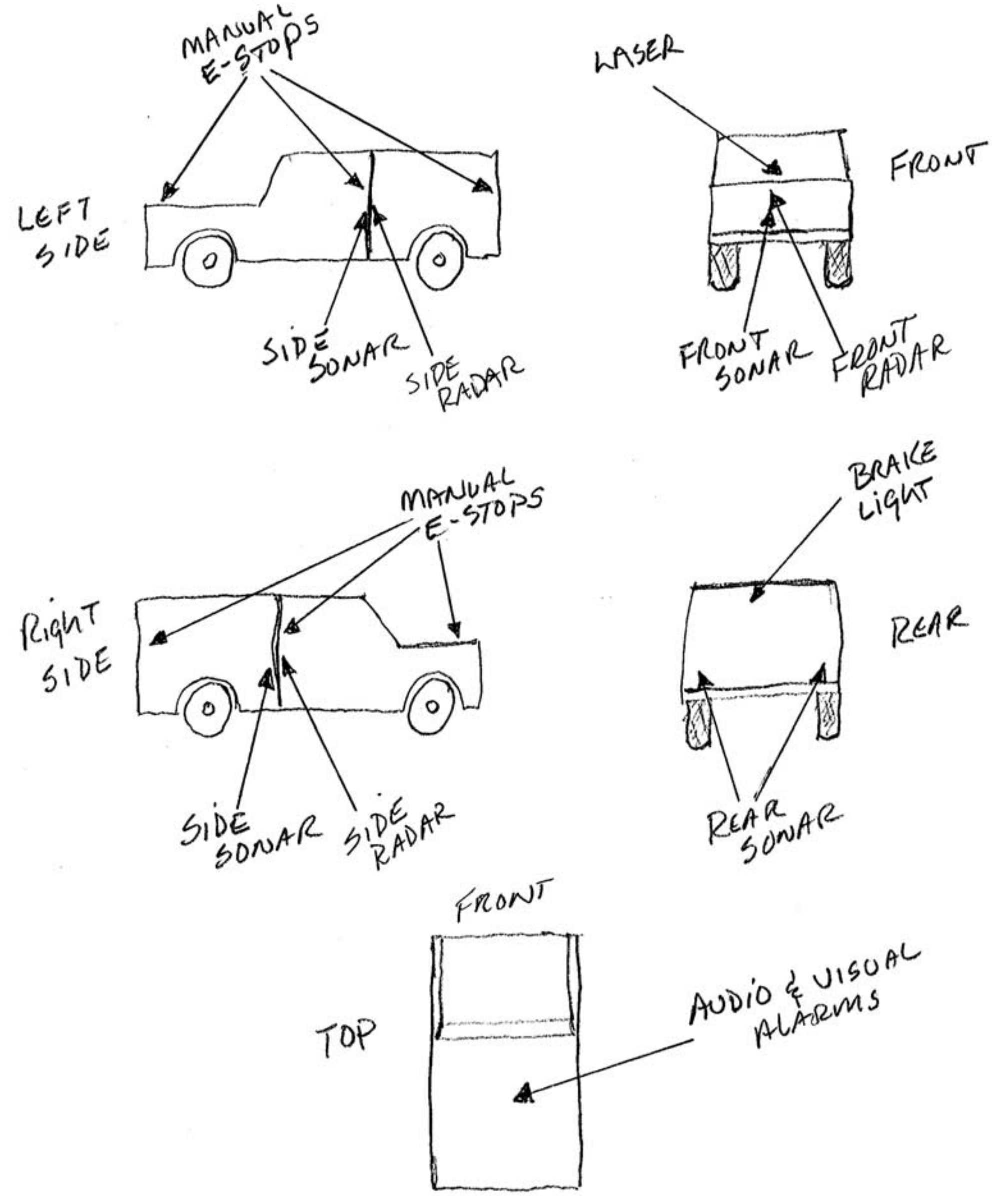
3.e.3 – Hearing protection for prolonged exposure to the audible warning device. Avoid staring into the laser ranger, although if you are in front of the vehicle while it is active you've got bigger problems.

3.f.1 – The Arctic Tortoise's ability to cause environmental damage is very similar to an off-road vehicle. These include such areas as: soil erosion and compaction, vegetation damage, degradation of cultural sites, harassment of wildlife, and destruction of desert biotic crusts. The autonomous nature of the vehicle enhances its ability to perform these types of damage. There is also the possibility of fluid leaks (oil, fuel, radiator fluid, etc).
Some vehicle modifications have been made to reduce possible damage: a skid plate has been added to protect the oil pan and engine, and racing-quality fuel cells have been installed. There has been no modification to the tires to help reduce the possible footprint of the vehicle, but the small amount of traffic the DARPA Grand Challenge intends to introduce should reduce possible damage to the environment.

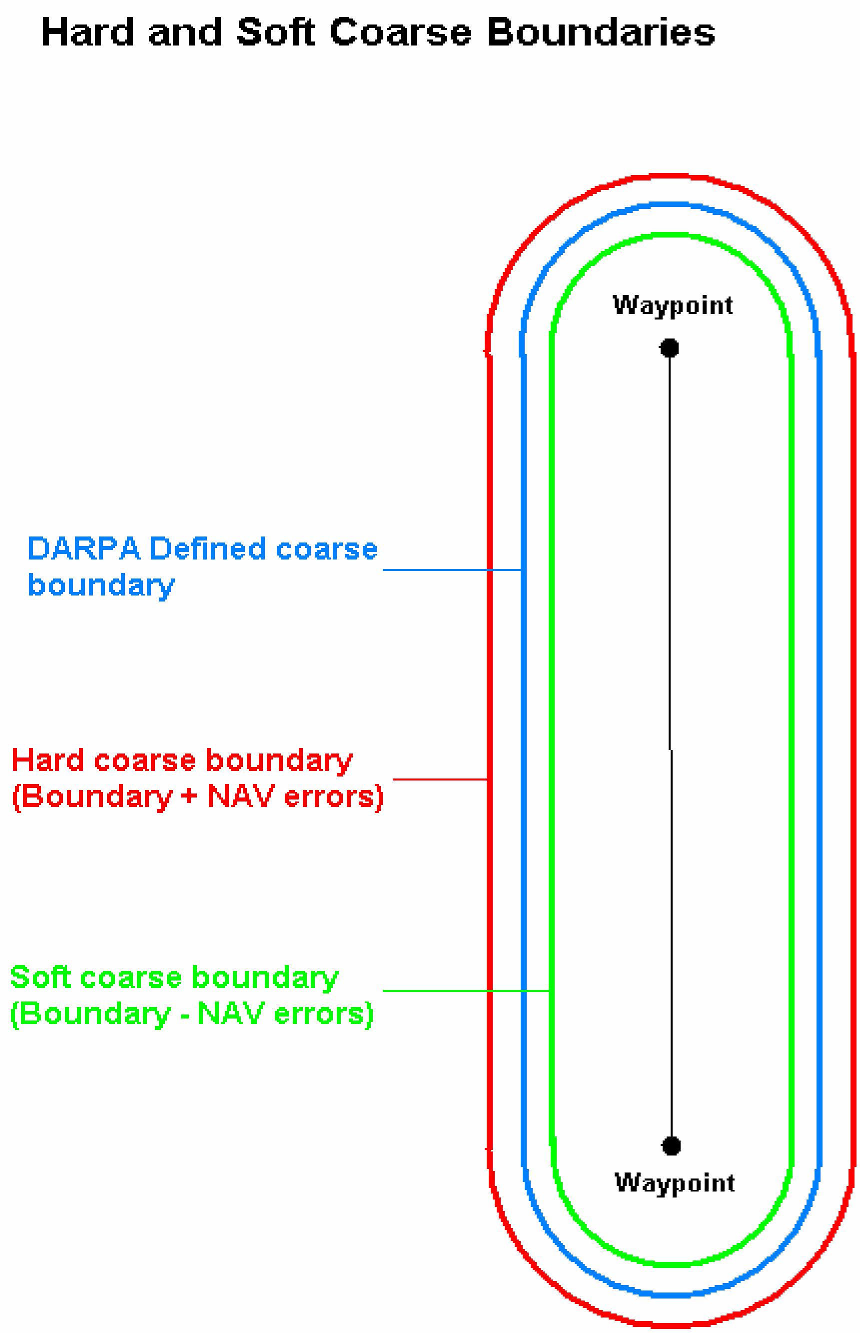
3.f.2 – Physical dimensions of the vehicle are 165" long, 70" wide and 70" tall. The vehicle is estimated to weigh 3300 lbs.

3.f.3 – The vehicle footprint is 200 sq in and the ground pressure at estimated weight is 16.5 lbs/sq in.

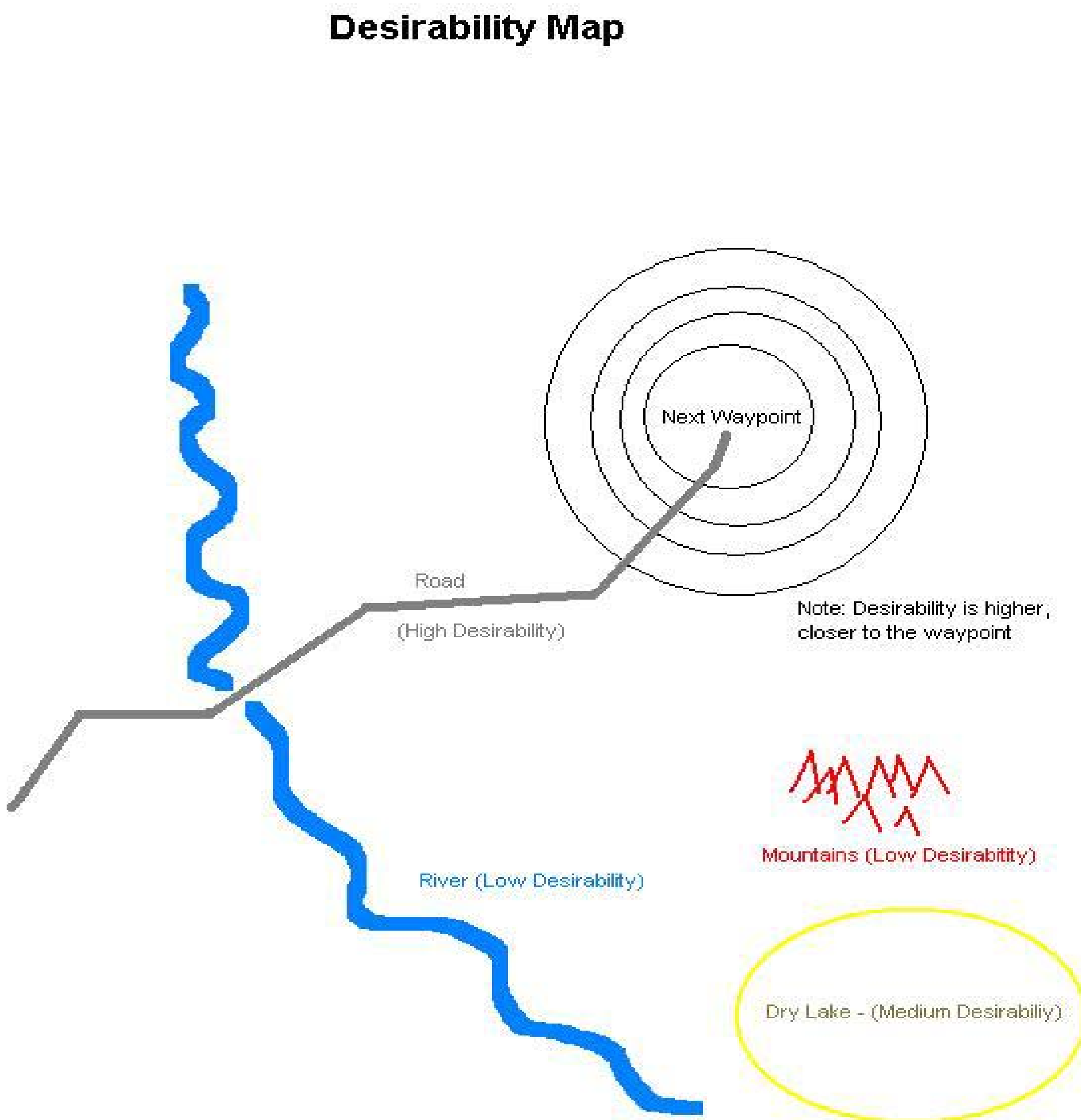
# ATTACHMENT A



# ATTACHMENT B



# ATTACHMENT C



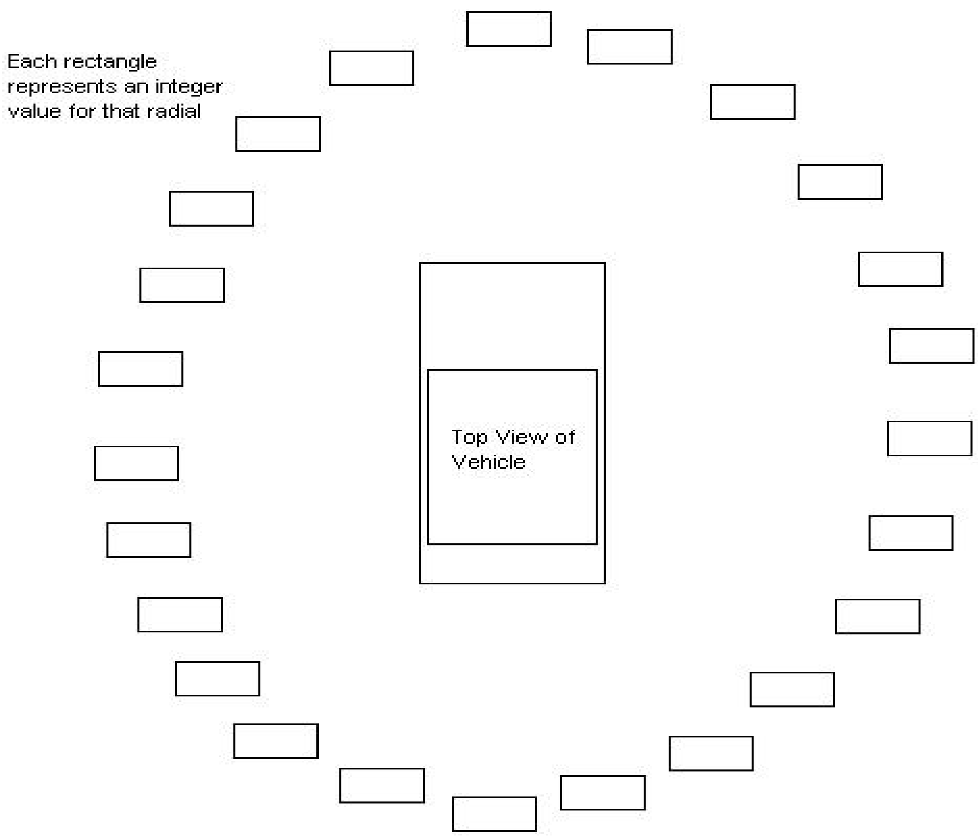
# ATTACHMENT D

## Heading Circle Data Representation

1 - Use Desirability map to calculate initial values for each radial in the circle

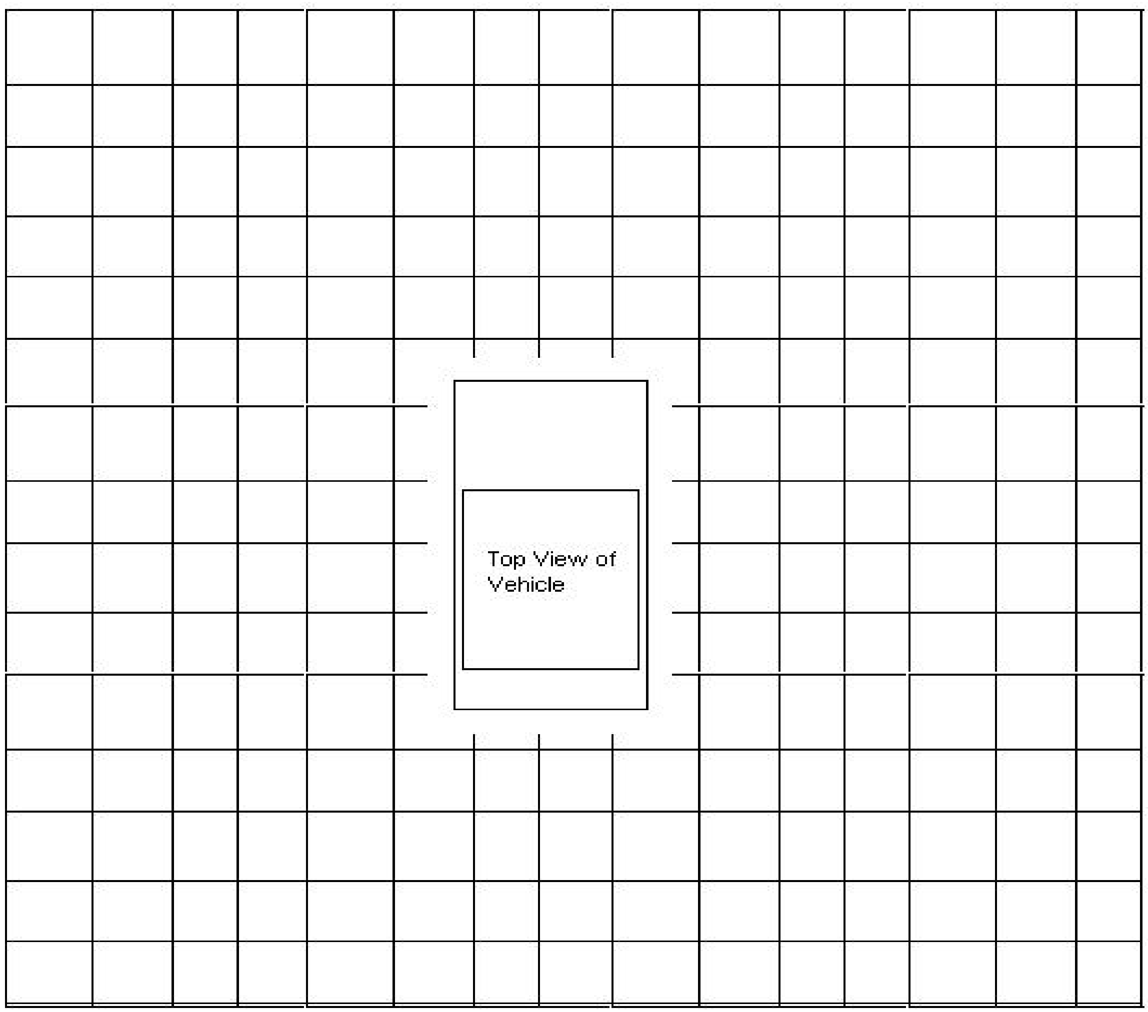
2 - Adjust numbers up or down, based on readings from the sensor grid.

3 - Find the maximum value in the heading circle and choose this heading as the direction of travel

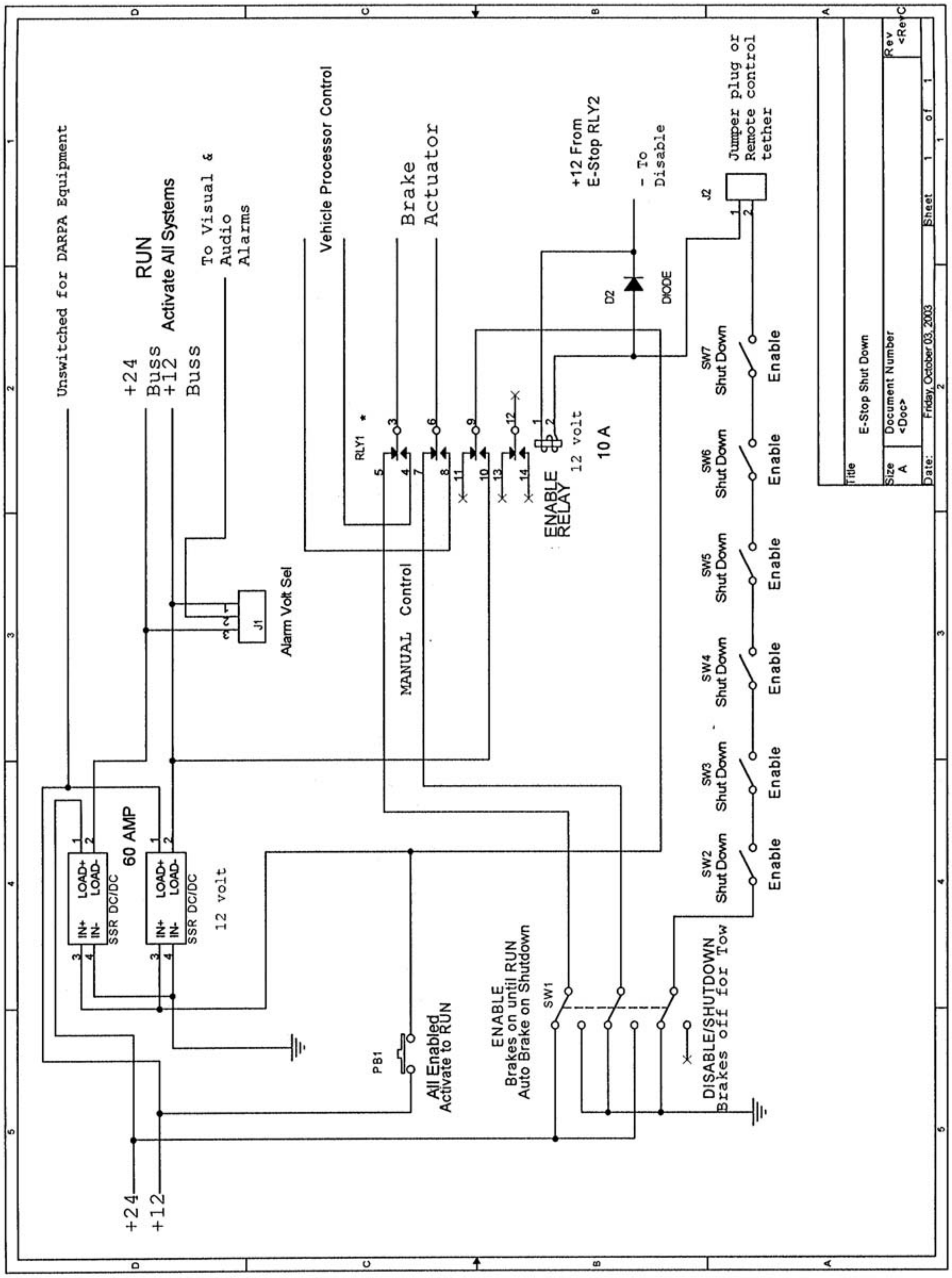


# ATTACHMENT E

## Sensor Grid Data Representation



# ATTACHMENT F



# ATTACHMENT G

*Parameter for the measurement of the accessible emission (AEL) at the laser measurement system type LMS 211-30206 (product family LMS Outdoor):*

| | |
|---|---|
| *Timebase:* | *100 s* |
| *Distance:* | *100 mm* |
| *Aperture:* | *50 mm* |
| *Plane angle:* | *<1.5 mrad* |
| *Wavelength:* | *905 nm* |

| | *Measured values* | *AEL Class 1* |
|---|---|---|
| *Single pulse* | *21.5 nJ* | *514 nJ* |
| *Reduced single pulse* | *21.5 nJ* | *24.6 nJ* |
| *Mean value* | *29.3 µW* | *1 mW* |

*The accessible emission limit (AEL) for laser class 1 is kept.*

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*Parameter for the measurement of the maximum permissible exposure (MPE) at the cornea of the eye at the laser measurement system type LMS 211-30206 (product family LMS Outdoor):*

| | |
|---|---|
| *Timebase:* | *100 s* |
| *Distance:* | *100 mm* |
| *Aperture:* | *7 mm* |
| *Plane angle:* | *<1.5 mrad* |
| *Wavelength:* | *905 nm* |

| | *Measured values* | *MPE (eye)* |
|---|---|---|
| *Single pulse* | *300 µJ/m²* | *12.9 mJ/m²* |
| *Reduced single pulse* | *300 µJ/m²* | *1.02 mJ/m²* |
| *Mean value* | *43.5 mW/m²* | *25.7 W/m²* |

*The limit for maximum permissible exposure (MPE) at the eye is kept.*

# ATTACHMENT H

1.c.2. The sensor computer integrates data from all sensors onto a single sensor grid. The grid consists of a two-dimensional array of 10cm squares, aligned with the vehicle, showing the space 100 M around the vehicle (refer to attachment E). A number from 1-10 is stored in each position of the array with higher numbers meaning harder obstacles. If two or more sensors pick up a return from the same place, the array numbers are added, resulting in a still higher number for that grid square. The routing algorithm is set up to route the vehicle to only lower number grid squares. If a grid square shows a sufficiently high number, the micro-routing algorithm will not go there, and will attempt to select a different route. The micro routing algorithm uses a fuzzy logic methodology to determine optimum heading. Several pieces of information are used by the router:

1 - Hard and soft coarse boundaries (see section 1.g.3)
2 - Heading to next waypoint
3 - Sensor grid
4 - Heading Desirability (Low number is most desirable) Based on map data (refer to attachment C)

these info are then added to provide a "heading circle". The software will look for the lowest number on the circle, make sure there is no hard obstacle in the way, and send this heading information to the control computer (refer to attachment D).

Vehicle speed is determined by an algorithm that assesses tactile sensors, obstacle imminence, required rate-of-turn, surface contour, expected terrain, and accelerometer data.
Confidence level must be high to attain maximum design speed.

# ATTACHMENT I

Rick
The EVT-300 typical power output is 3mw in a 12-degree wide beam. With this low power level no safety issues have ever been raised. We have FCC approval on the system. Here are the details:

## *FCC Compliance Statement*

This device is sold under a waiver of FCC (Federal Communications Commission) rules. Operation is subject to the following two conditions: (1)

This device may not cause harmful interference, and (2) this device must be able to accept any interference received, including interference that may cause undesired operation. Any interference that may be caused should be reported to your local FCC field office or to the Federal Communications Commission; Field Operations Bureau; 1919 M Street, N.W.; Room 734, Mail Stop 1500; Washington, D.C. 20554-0001.

Please let me know if you need any additional information.

Best regards,

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